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INTEGRAL GLASS ENCAPSULATION FOR SOLAR ARRAYS

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ABSTRACT

This is the tenth quarterly report under a program to develop integral glass encapsulation for solar cell arrays. This report describes the status of development of the techniques for employing electrostatic bonding in conjunction with terrestrial solar cells.

SECTION 1
INTRODUCTION

This is the tenth quarterly report under a JPL/DOE program for the development of permanent, integral glass encapsulation of terrestrial solar photovoltaic arrays by electrostatic bonding (ESB). The goal of this program is to develop electrostatic bonding to the point of being a cost-effective, practical, and automatable process that can be employed for large-scale production of arrays with lifetimes of more than 20 years. This report covers work performed during the period from 11 April to 10 July 1979.

Electrostatic bonding is a technique for forming permanent bonds between silicon (or other materials) and glass, without the use of adhesives. The bond is formed quickly and, once formed, can be stronger than either of the materials being joined. The inherent strength of the seal makes this an extremely durable encapsulation method, and the simplicity of the process makes it suitable for automation. Economic analyses have shown that electrostatic bonding can meet the 1986 LSA price goals.

Two basic types of electrostatically bonded modules were demonstrated during Phase II of this program, both based on an integral glass superstrate assembly. A number of conventional backings can be used to complete the encapsulation, or a back glass can be attached by electrostatic bonding for ultimate durability. Both module types have proved their reliability in accelerated environmental testing. In the present program phase, these fundamental designs will be scaled up to a larger size — to the maximum possible using existing equipment — and routine, consistent module production will be demonstrated.

SECTION 2
TECHNICAL STATUS

2.1 GENERAL

Efforts during this quarter concentrated on preparations for the scaleup from the four-cell modules produced in Phase II to larger six-cell assemblies. Among the areas receiving attention were the acquisition of large glass pieces, development of a larger, more efficient cell, the design of an improved terminal configuration, and the fabrication of bonding fixtures. All of these efforts are approaching completion, and initial bonding experiments are ready to begin.

2.2 GLASS FOR ELECTROSTATIC BONDING

One lot of hand-rolled 7070 glass, comprising two hundred sixty 5.7 inch x 7.7 inch pieces, has been received from Corning Glass Works. Although the pieces were flattened at Corning, they are not flat enough to be ground and polished. Initial experiments indicate that the bonder can be used to flatten the pieces to an acceptable degree. It is expected that the bonder-flattened glass will be usable for module fabrication without further processing, in spite of a somewhat rough surface.

2.3 MODULE DEVELOPMENT

2.3.1 Advanced Module Cell

The design of a new cell, larger and more efficient than that used in four-cell bonded modules, was discussed in Quarterly Report No. 9. A few sample cells were made during this quarter, but the lack of complete evaporation fixtures prevented the processing of complete lots. The necessary fixtures are now on hand, and a test lot of cells is in process.

The I-V characteristic of one of the sample cells is shown in Figure 1. As expected, the new cell has greater power output than the cells presently used, due both to its larger area (from 5 cm square to 5.64 cm square) and to an efficiency improvement of at least one percentage point.

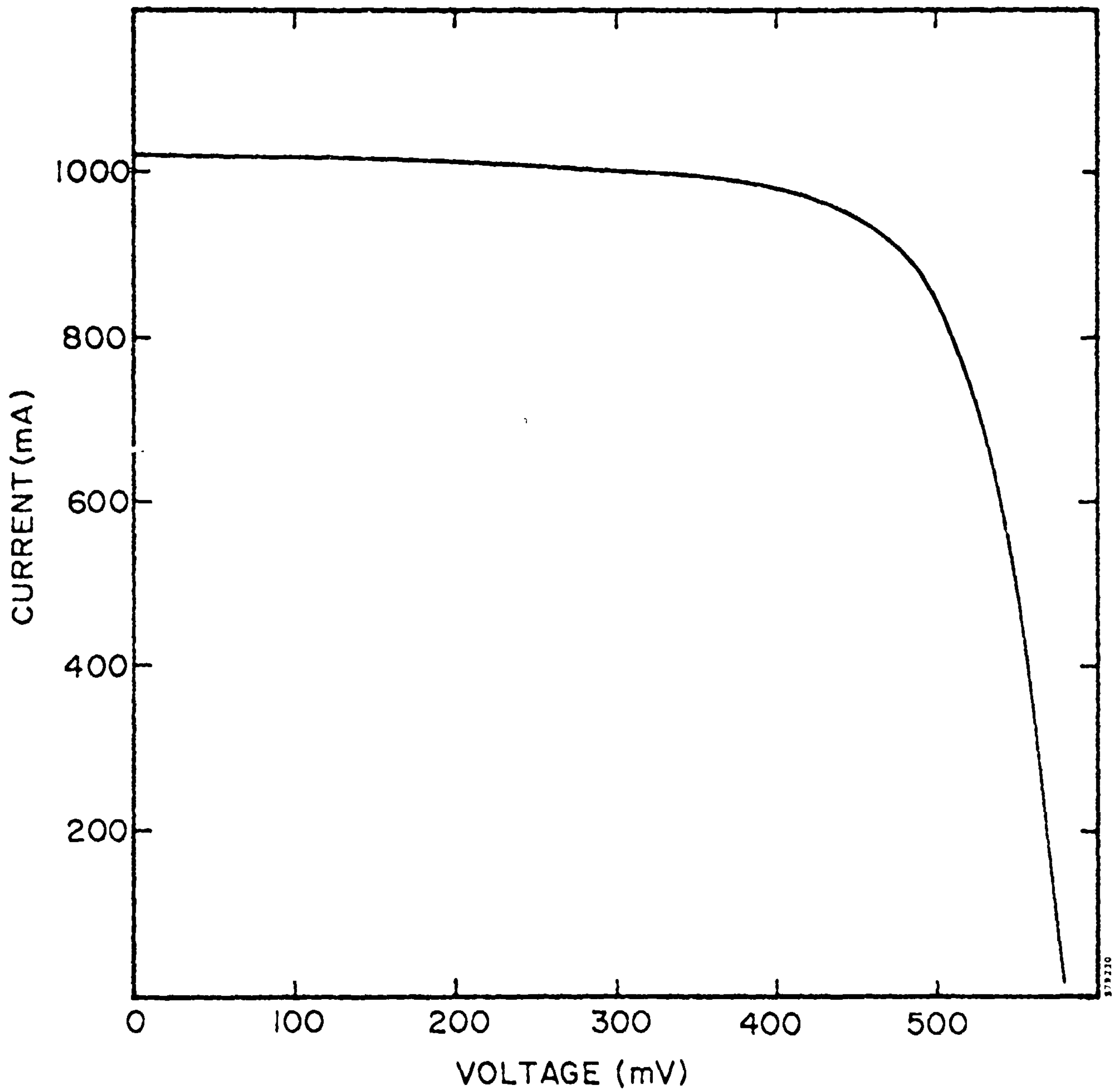

FIGURE 1. AM0 I-V CURVE OF SAMPLE ADVANCED BONDER CELL

2.3.2 Output Terminal Development

One of the advances made during Phase II of this program was the development of an output terminal configuration that preserves the hermetic seal of an all-glass-encapuslated module, while allowing easy electrical access. The structure is based on an aluminum foil pad electrostatically bonded to both front and back glasses. A brass stud is then soldered to the pad, while passing through a hole in the front glass for additional mechanical support. A sketch of this configuration appears in Figure 2.

Drilling holes in the front glass necessarily violates its structural integrity and weakens its resistance to stress. Moreover, the rigid solder joint, formed at elevated temperature, leaves residual stresses on cooling, due to the thermal expansion difference between the glass and the massive metal terminal (cracks in the glass sometimes result).

To eliminate these drawbacks without sacrificing the advances already made, a new terminal design is needed. For Type I modules, the sealing properties of the aluminum pads are not needed, since a bonded back glass is not used. The pads have therefore been eliminated from the new Type I terminal design, which is sketched in Figure 3. The use of EVA prevents stress from arising, while the large area of adhesion provides mechanical strength without damage to the front glass assembly. A prototype terminal of this type has been made and assembled on a four-cell module to demonstrate the concept. A similar design for Type II modules, retaining the sealing characteristics of the bonded foil, is in preparation.

2.3.3 Bonding Fixtures

Alignment electrodes for the bonding of six-cell modules have been fabricated. They incorporate insulating pins to position the cells and shallow slots to accommodate the interconnect ribbons. The design is identical in concept to that used for four-cell modules, which has been extremely successful in speeding processing, increasing packing density to 95 percent, and eliminating failures due to interconnect breakage and cell slippage.

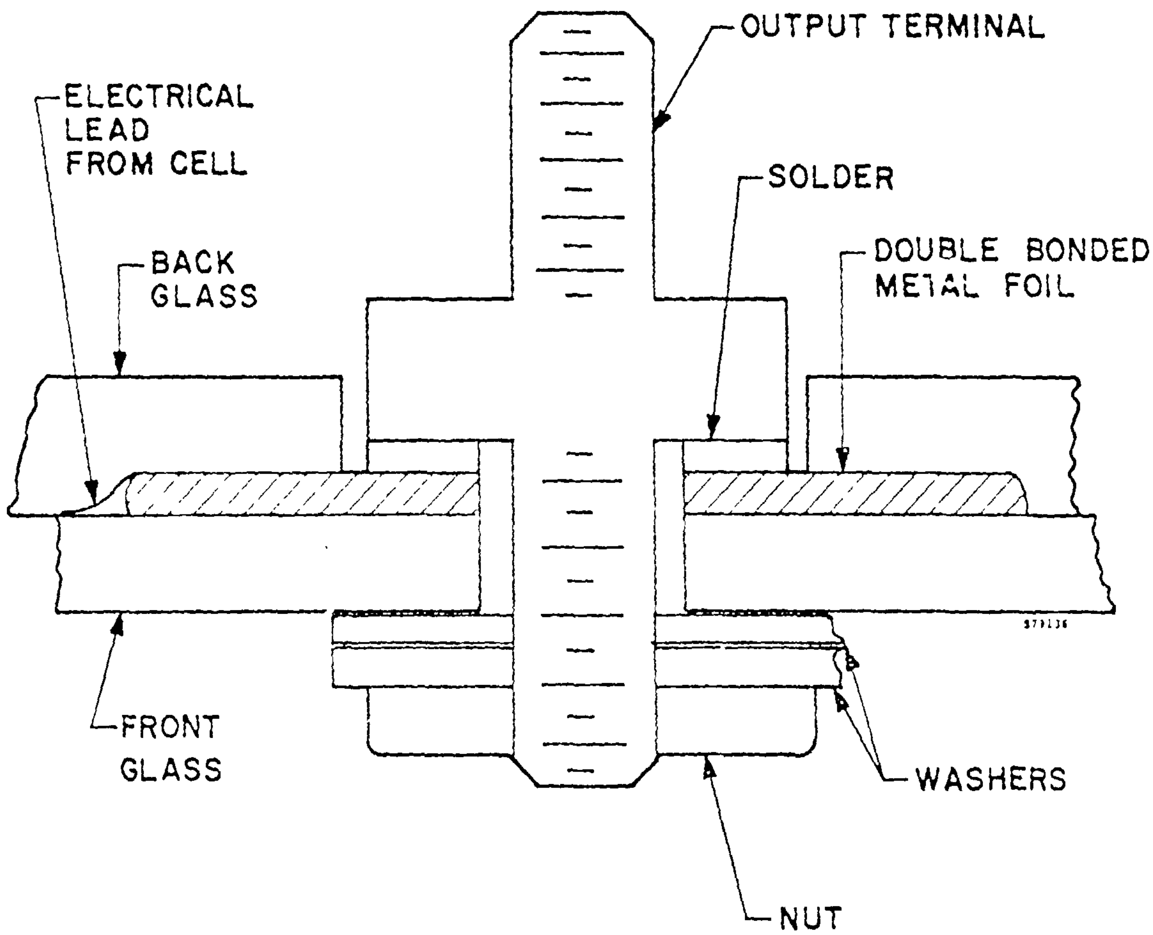

FIGURE 2. INTEGRAL MODULE OUTPUT TERMINAL DESIGN - PHASE II

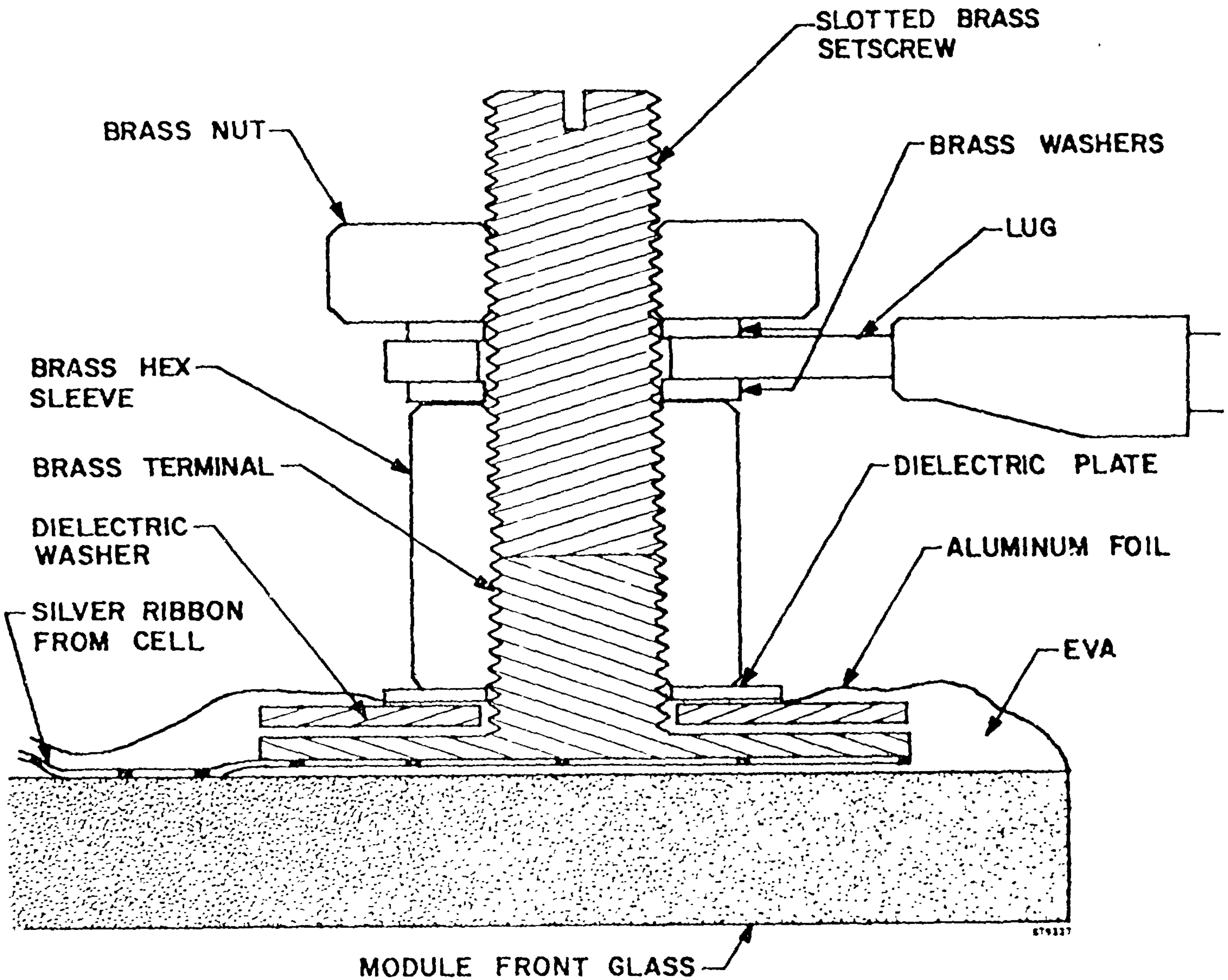

FIGURE 3. ADVANCED TYPE I TERMINAL DESIGN

2.4 FACILITY MODIFICATIONS

A heater has been added to the preheat/anneal stage of the bonder, to slow the radiant cooling of samples and permit the attainment of higher annealing temperatures. Prior to the modification, it was difficult to reach temperatures higher than about 450°C, well below the annealing point of 7070 glass, 496°C. As a result, the cooling rate of the sample through the annealing range could not be controlled, and the modules evidenced residual stress due to this rapid nonuniform cooling. With the new heater, temperatures above 500°C can easily be reached, and the annealing of modules should be accurately controlled.

2.5 PREFORMED METALLIZATION DEVELOPMENT

Work has continued on preformed mesh metallization trapped by ESB as a cell front contact. Such metallization has the potential for low cost, in that the metallization is applied during the encapsulation step rather than in a separate process step. During Phase II, cells with curve fill factors as high as 69.4 percent had been produced, using silver mesh with a strand width of 1.9 mils (48 micrometers).

Several test modules were made with four cells, all using trapped wire mesh as the front contact. Figure 4 shows the I-V curve of one of these modules. Although the total-module curve fill factor is 48 percent, the best cell had a fill factor of 62 percent and a total power of 234 mW (see Figure 5), indicating that considerable improvement is possible.

Work also continued in looking at alternative meshes. The best mesh identified in Phase II was 1.9 mil silver mesh. We have now tested 2.8 mil silver mesh with the same line density (20 lines/inch). The best cell produced (see Figure 6) had a considerably better performance with a curve fill factor 74 percent and a 5 percent improvement in peak power over the previous best cell. The sample was made without a titanium overcoat or hydrofluoric acid wafer clean before bond, both of which have resulted in improvements in performance over the previous mesh.

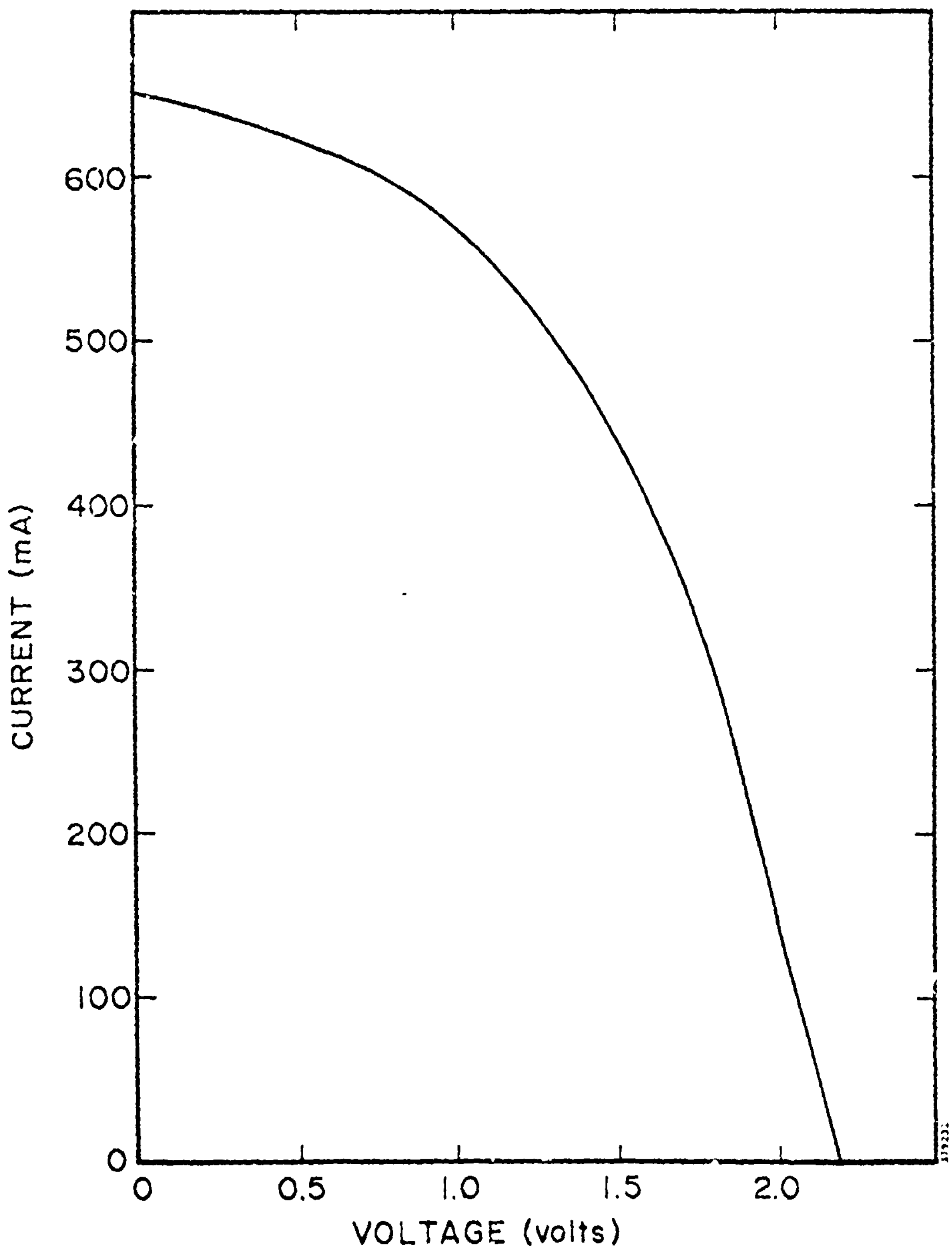

FIGURE 4. AM0 I-V CURVE OF FOUR-CELL MODULE WITH TRAPPED MESH METALLIZATION

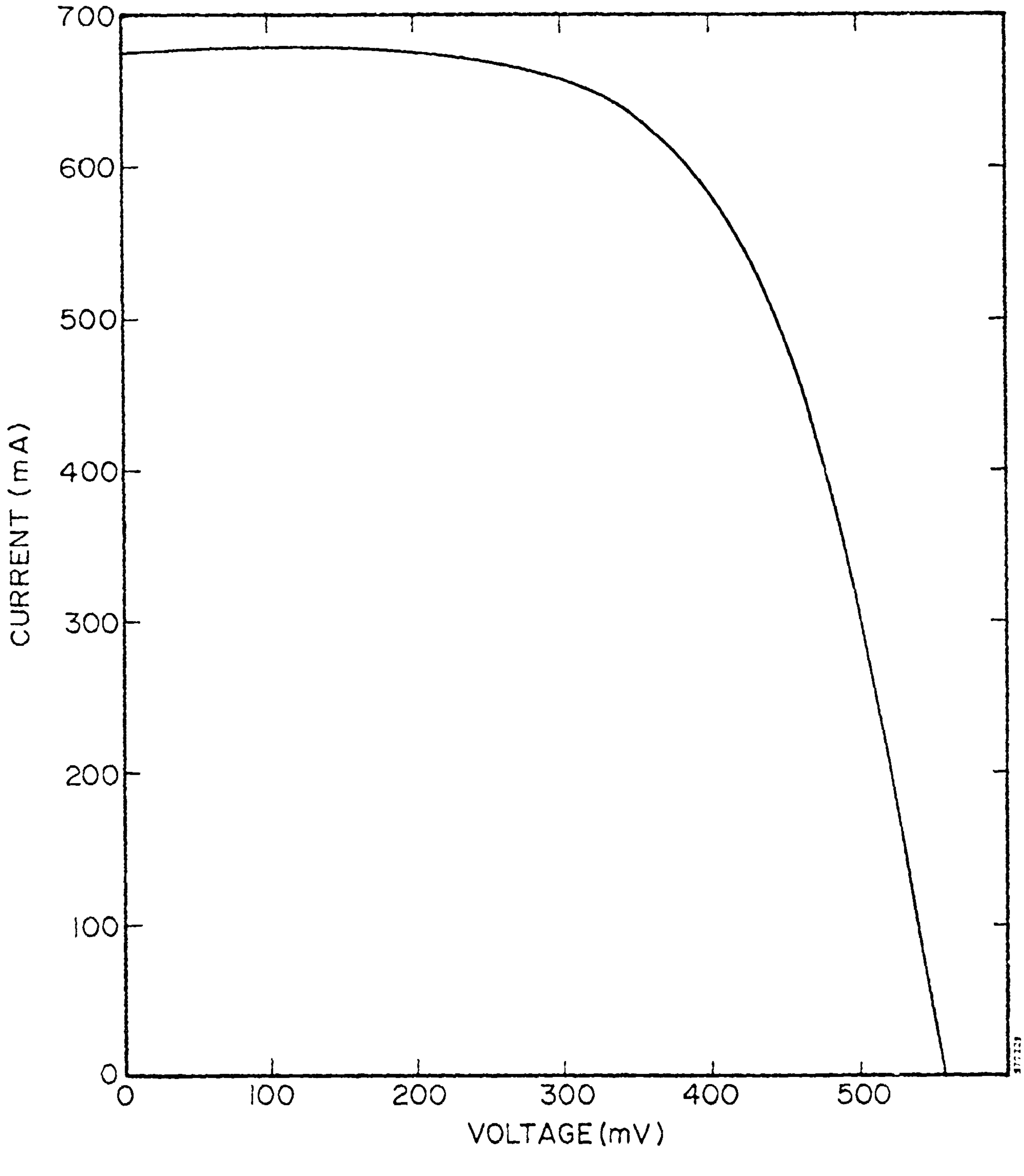

FIGURE 5. AM0 I-V CURVE OF CELL NO. 1 FROM FOUR-CELL MODULE WITH TRAPPED MESH METALLIZATION

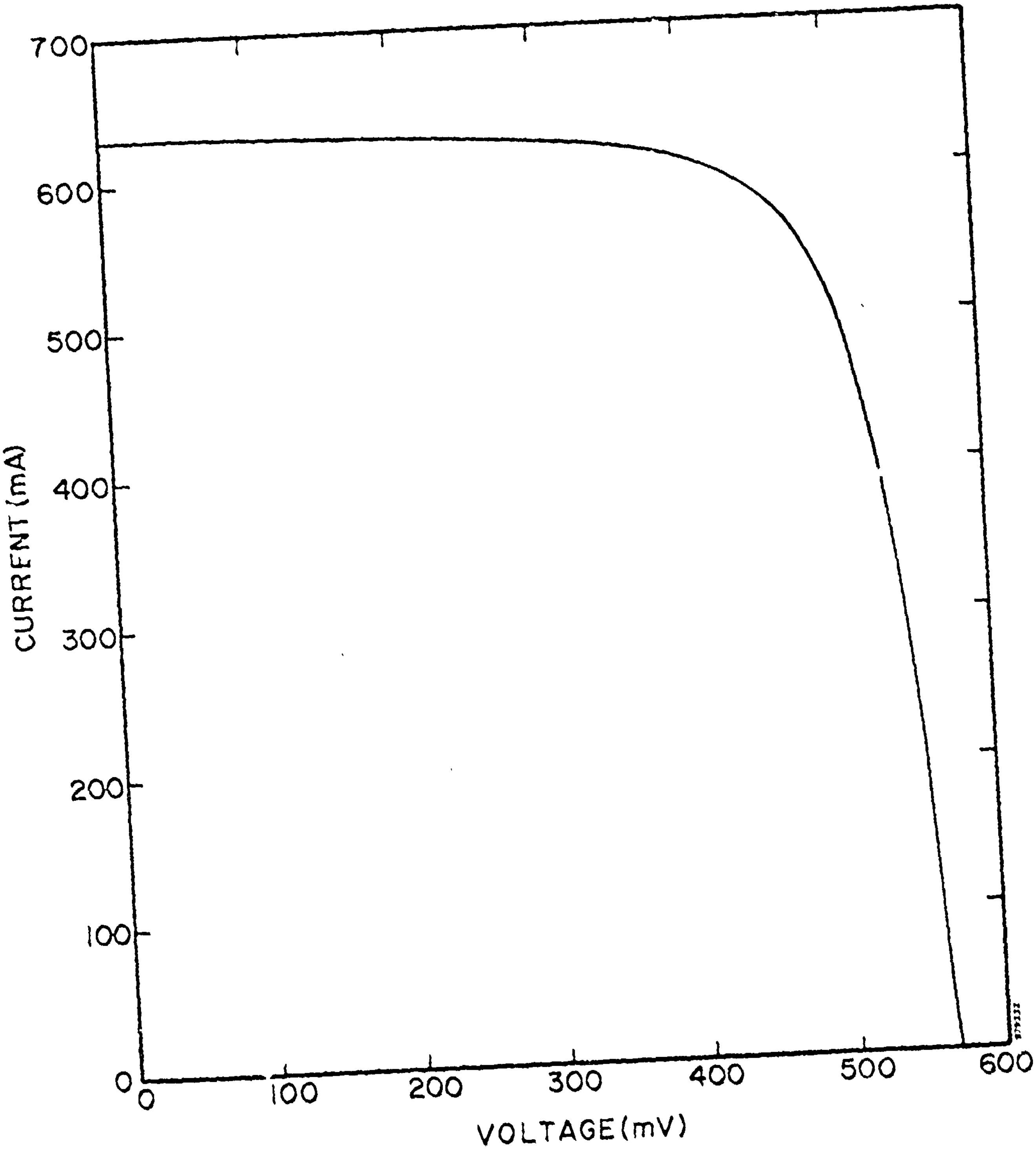

FIGURE 6. AM0 I-V CURVE OF CELL WITH 2.8 MIL SILVER MESH METALLIZATION

Also tested was a woven molybdenum mesh. Molybdenum is not currently available in electroformed mesh. The molybdenum mesh tested had a wire diameter of 1.6 mils (40 micrometers) with a line density of 42 lines/inch (17 lines/cm). Since woven mesh has overlapped lines (unlike electroformed mesh, where all intersections are planar), the maximum projection of this mesh is 3.2 mils (81 micrometers), making the mesh difficult to accommodate. The best cell to date made with this mesh has a curve factor of 63.5 percent.

More measurements of mesh to silicon contact resistance were made using the test setup shown in Interim Report 2. Contact resistances between 26.9 and 53.5 milliohms-cm^2 were recorded, with an average value of 34.9 milliohms-cm^2.

2.6 MODULE DELIVERIES

The delivery of four-cell modules for Phase II continued this quarter. Eighteen bonded Type I assemblies were delivered to JPL for application of EVA/aluminum foil backing and incorporation into three standard size minimodules. A representative I-V curve appears in Figure 7. The use of an alignment electrode has made the fabrication of well-bonded four-cell assemblies with good electrical characteristics a routine process. Process yield exceeded 80 percent during this fabrication run.

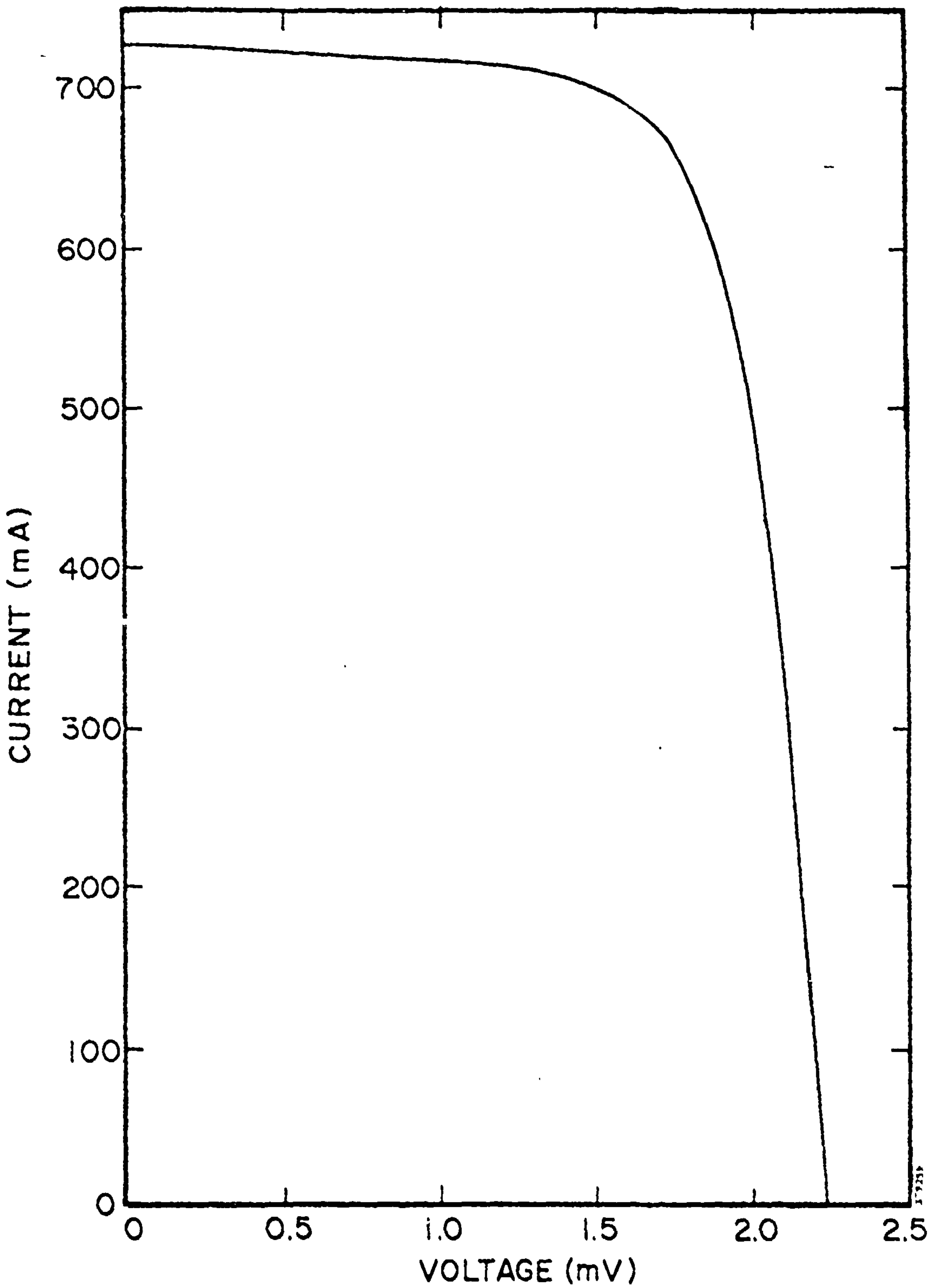

FIGURE 7. AM0 I-V CURVE OF FOUR-CELL TYPE I MODULE

SECTION 3
CONCLUSIONS

During this period the following progress can be reported:

1. Routine production of four-cell modules has been demonstrated, with reproducible cell and interconnect positioning and reduced operator handling.
2. Nearly all of the necessary materials and fixtures are on hand for the bonding of six-cell modules.
3. An additional heater has been added to the bonder giving improved control over the annealing of bonded modules.
4. A new output terminal for Type I modules has been designed and demonstrated.
5. Improved results have been obtained with preformed wire mesh metallization. Best fill factors are now 74 percent.

SECTION 4
PROGRAM PLAN

During the next quarter, glass flattening and bonding experiments will be conducted, and production of the new bonder cell will begin, leading to the production of the first deliverable six-cell modules. Work with preformed metallization will continue.